

ON DEUTERIUM GENERATION IN THE EARLY SOLAR SYSTEM. G. K. Ustinova, Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, Moscow, 117334, Russia.

As obtained, in the conditions of shock wave propagation at the stage of forming the solar system only $\leq 40\%$ of the average abundance of deuterium could be generated. Preliminary contamination of the protosolar nebula through the deuterium produced in the similar processes at about ~ 10 earlier supernova explosions should be supposed.

In our previous works a powerful mechanism of forming small-scale heterogeneity of the protosolar matter has been revealed [1–3]. Indeed, in the conditions of shock wave propagation, which accompanied many processes in the early solar system, the power law spectrum of energetic particles $F(>E_0) \sim E^{-\gamma}$ was more rigid ($\gamma \sim 1-2$, whereas $\gamma \sim 2.5$ for galactic cosmic rays, and $\gamma \sim 3-6$ for solar cosmic rays), which led to the increase of their integral fluxes above E_0 up to two orders of magnitude, as well as to the change of production cross sections of the isotopes, the excitation functions of which were sensitive to the shape of the spectrum. As an example, the isotope production rates can vary within seven orders of magnitude when γ undergoes a change in the range 1.1–6.0. The subsequent analysis of the abundances of Li, Be, and B isotopes as well as the isotopic anomalies of Ne-E, dinuclides Na-22, Al-26, and Mn-53, respectively) has suggested that $\gamma \sim 1.2$ at the stage of formation of the solar system, which is in accordance with the gamma-astronomy

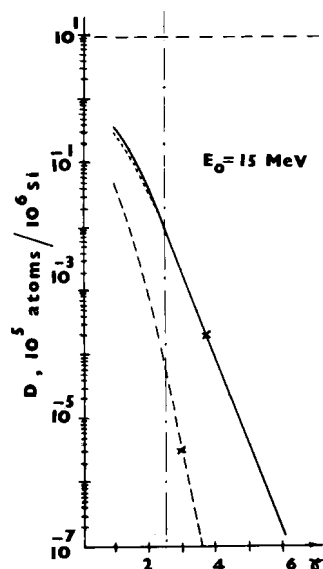


Fig. 1. Generation of deuterium in the reactions of $^4\text{He}(p,D)^3\text{He}$ (dotted curve); $^1\text{H}(p,p^+)D(x10)$ (dashed curve) and in both ones (solid curve) with accelerated protons of power law spectrum depending on spectral index γ above $E_0 = 15$ MeV (dashed horizontal line marks the average abundance of deuterium in the solar system [5]; crosses are the galactic cosmic ray contributions to D production in these reactions over $5.4 \cdot 10^9$ y before solidification of matter).

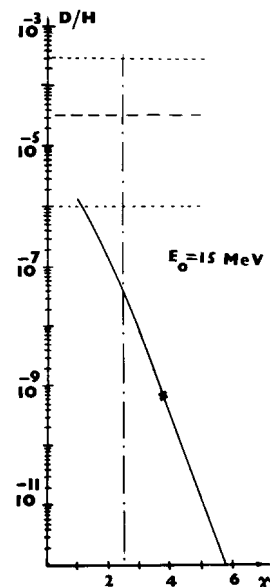


Fig. 2. D/H as formed in the considered processes (a cross is GCR contribution; dashed line is the average solar system ratio [5]; lower and upper lines are those in a young star [6] and in comet P/Halley [12]).

investigation of some supernova environs [4]. It means that shock wave acceleration of particles was very essential in the early solar system, and its effects have to present anomalies of some other isotopes.

First of all, it concerns the origin in deuterium which galactic, protosolar, and the solar system abundances are constantly discussed. The average D abundance in the solar system is $9.49 \cdot 10^5$ atoms/ 10^6 Si and $D/H \sim 3.4 \cdot 10^{-5}$ [5]. The presolar-system abundance obtained from the giant planet atmospheres is $D/H \sim (1-4) \cdot 10^{-5}$; the present-day interstellar abundance is $D/H \sim (0.8-2) \cdot 10^{-5}$; and the stellar atmosphere value for a young, evolved star is $D/H < 10^{-6}$ [6]. The observed inhomogeneity of D/H distribution is conditioned, in most cases, by the processes of chemical and physical fractionation; nevertheless, it constrains the choice of possible D sources. Indeed, the cosmological nucleosynthesis could provide $D/H \sim 10^{-5} - 10^{-4}$ [6], but a search for deuterium lines in a few halo dwarfs was fruitless [7]; besides, that D/H distribution had to be homogeneous, as well as, perhaps, from galactic nucleus activity. Therefore, owing to the D/H inhomogeneity, locally variable astrophysical processes are preferred, as D sources. Because thermonuclear D cannot be conserved, its production in spallation reactions during star activity is of paramount importance [8]. Many works are devoted to the problem including those that took into account some peculiarities of shock wave accompaniment. Nobody has examined the effect of rigidity increase of ac-

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celerated particle spectrum during shock wave propagation on D production, as described in the beginning of the paper, yet. In this work the reactions of ${}^4\text{He}(p,D){}^3\text{He}$ and ${}^1\text{H}(p,\pi^+){}^2\text{D}$, for which the cross section data are available [9,10], have been considered in those conditions. As can be derived from Fig. 1, at the stage of forming the solar system when the light elements and the extinct radionuclides were generated on rigid irradiation ($\gamma \sim 1.2$) only 3.7% of the average abundance of deuterium have been produced in those reactions, the contribution of the second one being negligible, as well as that of galactic cosmic rays being not essential. The other possible reactions leading to D generation are ${}^4\text{He}(p,pD){}^2\text{D}$ and ${}^4\text{He}(p,2pn){}^2\text{D}$. The contribution of the first one can be only similar or less than that of ${}^4\text{He}(p,D){}^3\text{He}$, whereas that of the second one with only one bound particle in the finish state can be, in principle, up to an order of magnitude higher. Therefore, in the conditions of shock wave propagation in the early solar system (e.g., due to the last supernova explosion) no more than ~40% of the average abundance of D could be generated. However, the protosolar nebula is supposed to be precontaminated

through the products of about ~10 earlier supernova explosions [11] including, perhaps, D produced in the considered processes. In conclusion, it is interesting to note in Fig. 2 that D/H formed in the rigid irradiation conditions corresponds to the ratio measured nearby a young, evolved star (F0 Ib) [6].

References: [1] Ustinova G. K. (1995) *Sol. Syst. Res.*, 29, 298; (1996) *Sol. Syst. Res.*, 30, N6. [2] Ustinova G. K. (1995) *Proc. 24th ICRC, Roma* 3, 204; (1995) *LPS XXVI*, 1435; (1996) *LPS XXVII*, 1351. [3] Lavrukina A. K. and Ustinova G. K. (1992) *Sol. Syst. Res.*, 26, 45; (1993) *Geokhimia*, N3, 322. [4] Ginzburg V. L. and Dogel' V. A. (1989) *Uspekhi Phys. Nauk*, 158, 3. [5] Anders E. and Grevesse N. (1989) *GCA*, 53, 197. [6] Boesgaard A. M. and Steigman, G. (1985) *Ann. Rev. Astron. Astrophys.*, 23, 319. [7] Spite M. and Spite F. (1985) *Ann. Rev. Astron. Astrophys.*, 23, 225. [8] Hayle F. and Fowler W. A. (1973) *Nature*, 241, 384. [9] Hayakawa S. et al. (1964) *J. Phys. Soc. Jap.*, 19, 2004. [10] Overseth O. E. et al. (1964) *Phys. Rev. Lett.*, 13, 59. [11] Reeves H. (1982) *Protostars and Planets*, Moscow, 453. [12] Eberhardt P. et al. (1995) *Astron. Astrophys.*